AEGIS Autonomous Targeting for ChemCam: Protecting the Rover and the Instrument

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ChemCam Instrument
on the Curiosity rover

- Laser-Induced Breakdown Spectrometer (LIBS) with Remote Micro-Imager (RMI)
- Gives geochemical composition of rock targets at ranges up to 7 metres
- Over 440,000 measurements on 1500 targets on Mars since 2012
- Targets selected by specialists on Earth, inspecting images returned from Mars
- Joint development of
  - Los Alamos National Laboratory (LANL, Los Alamos)
  - Institut de Recherche en Astrophysique et Planétologie (IRAP, Toulouse)

AEGIS Intelligent Targeting System

"Automated Exploration Gathering Increased Science"

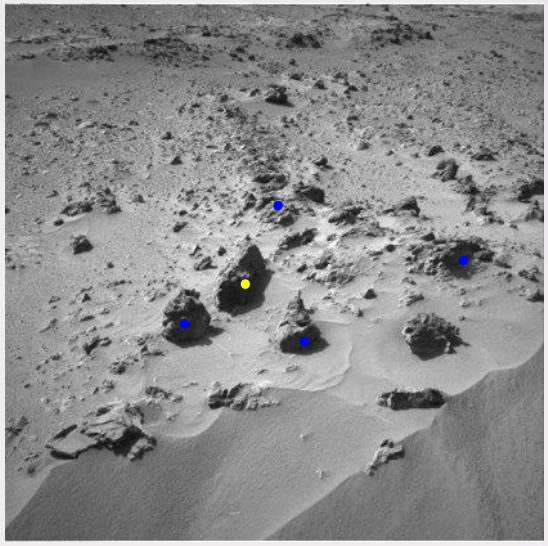
AEGIS was first flown on MER Opportunity in 2010

- Autonomous target selection for PanCam (mid- or post-drive)

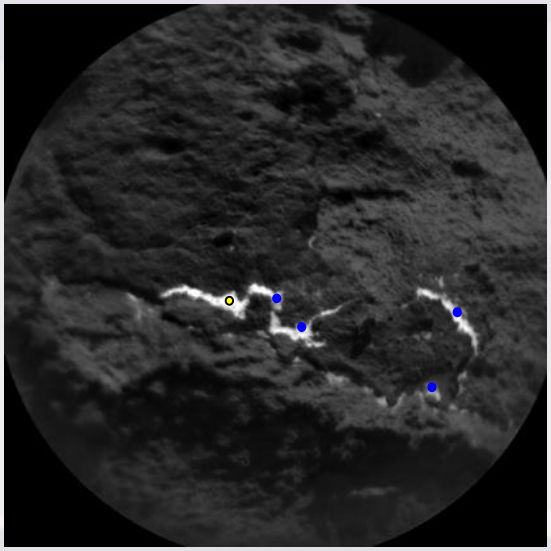
Now in use for ChemCam on MSL, in two roles

- Autonomous target selection in NavCam images
- Autonomous pointing refinement in RMI images

NavCam



RMI



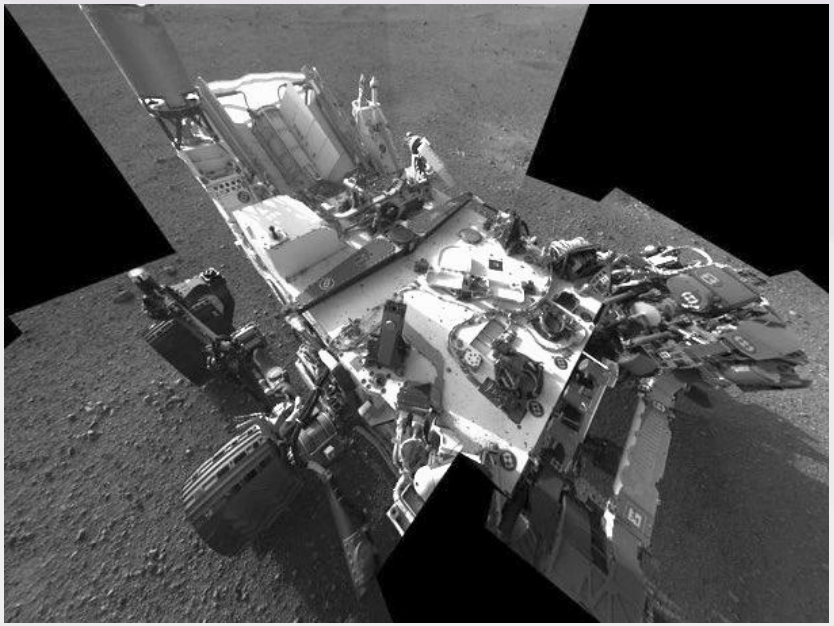
ChemCam Collision Safety

"Protect the Spacecraft"

ChemCam must not be allowed to shoot the rover.

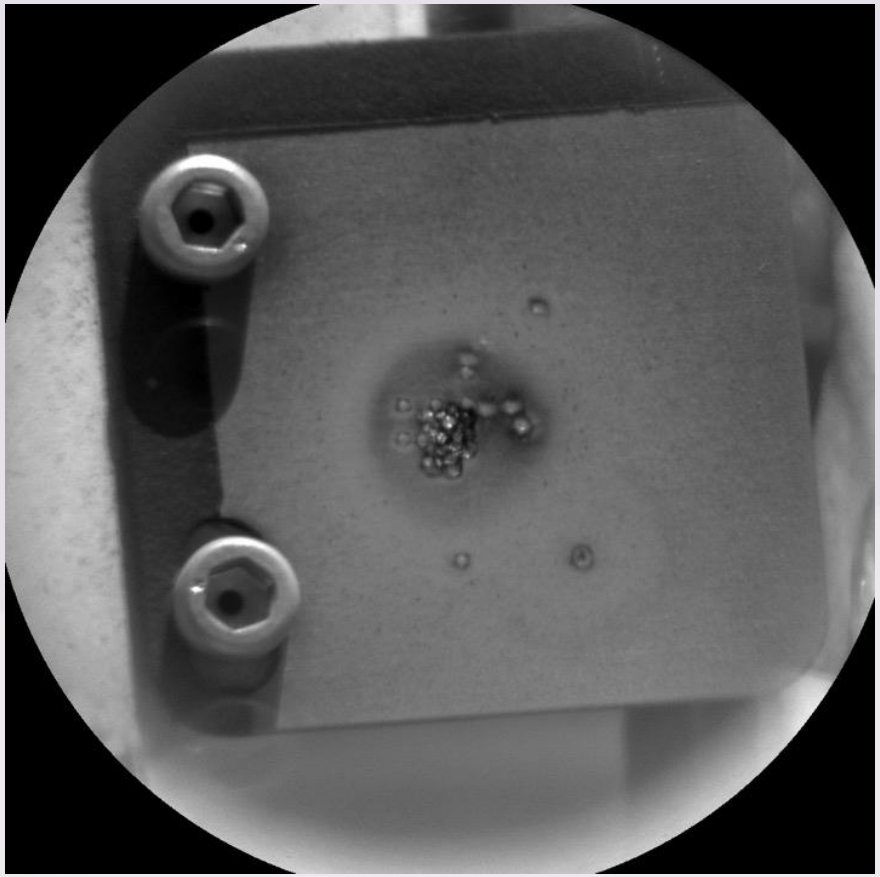
AEGIS software handles collision prevention automatically in some cases

Supported by collision safety procedures for operators, and training for instrument and mission ops personnel



Mast view of rover, sol 2

Much of the rover hardware is in reach of ChemCam's laser, including sensitive instruments. The robotic arm (stowed in this view) must also be avoided.



ChemCam calibration target, sol 1126

This is what happens when ChemCam's powerful laser hits a plate made of solid titanium.

It is important to prevent ChemCam from shooting the rover anywhere but on the calibration target.

ChemCam Sun Safety
"Protect the Instrument"

- ChemCam is sensitive and cannot be pointed at the sun
  - Not even transiently when slewing between LIBS targets
  - Must account for potential fault conditions: Exclude anywhere the sun could be anytime in the next ~month.
- All ChemCam targets/slews carefully planned and selected
- Sun-safety protections exist for science operations:
  - Operations rules and procedures
  - On-board software
  - Special focus position
- New sun-safety procedures for autonomous-targeting ops
  - Maximize science flexibility and targeting options
  - Minimize complexity
    - Potential for errors
    - Hesitation to use AEGIS if it appears complicated
- On-board commands can exclude portions of the Az/El space around the rover

Sunset at Gale Crater, sol 956. Colour MastCam image

Target distance rules

"Protect the instrument" & "Get good science data"

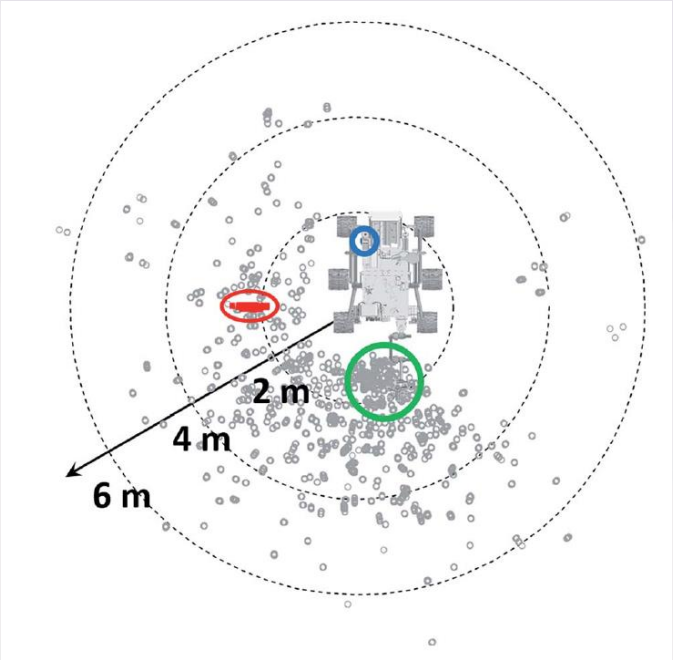
Risk to instrument from firing too close. (~2.2 m)

Science data becomes too noisy beyond ~7 m

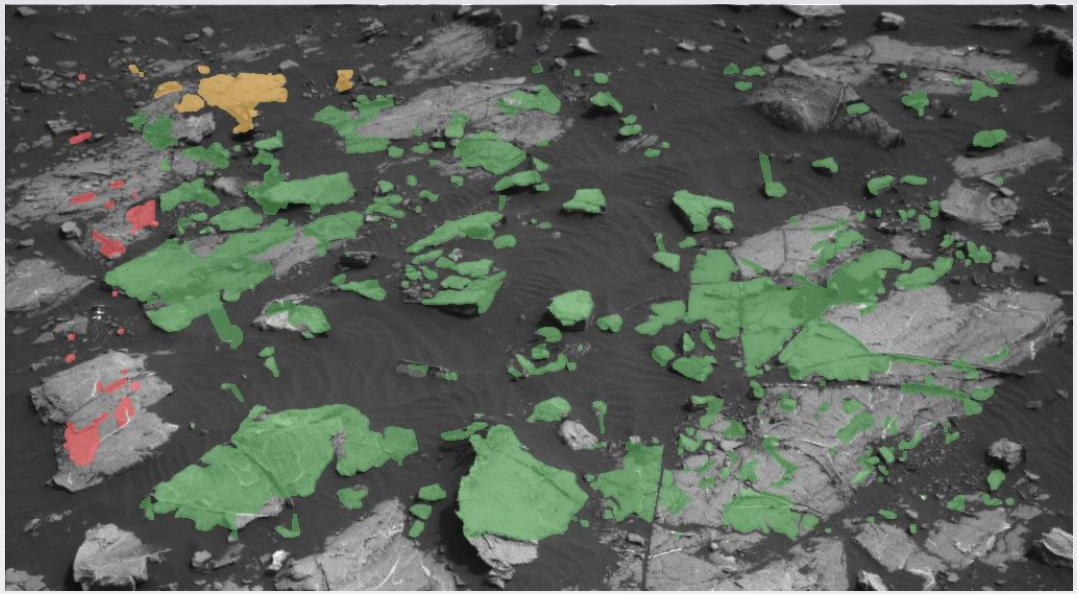
Poor laser focus can cause loss of observation

AEGIS computes stereo range

- Rejects targets with poor range estimate
- Filters targets outside useful range of ChemCam



Distribution of ChemCam targets



Example of stereo filtering

Red: Rejected for poor stereo estimation.
Yellow: Rejected out of range
Green: Passed filter

Flight System Validation
"Prove it works on Mars"

- **Each minute of time on Mars is a precious opportunity**
  - A large team of experts carefully consider each observation

- **The Curiosity rover is a sensitive, valuable, unique flight system**
  - The standard for protecting the rover is very high

- **The deployment of AEGIS means:**
  - Letting the computer choose science targets, instead of scientists
  - Placing a powerful laser under control of an intelligent computer system

- **AEGIS checkout activities were designed to verify and validate the *software*, its *safety measures*, and its *effectiveness*, on Mars, after extensive testing on Earth**
  - Does it run correctly in all modes and circumstances?
  - Does it protect the instrument and the vehicle?
  - Does it pick good targets?
  - Does it point ChemCam correctly to hit those targets & make good measurements?

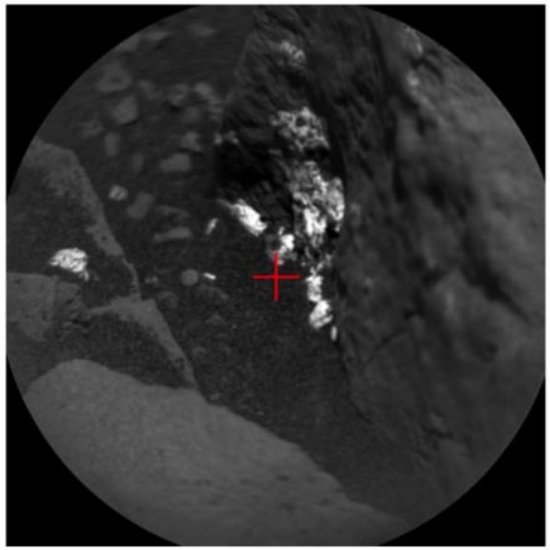
- **7-step progressive checkout plan**
  - Worked up from running code only, to taking images of targets, to firing the laser at them
  - Plan approved by MSL mission authorities and ChemCam team

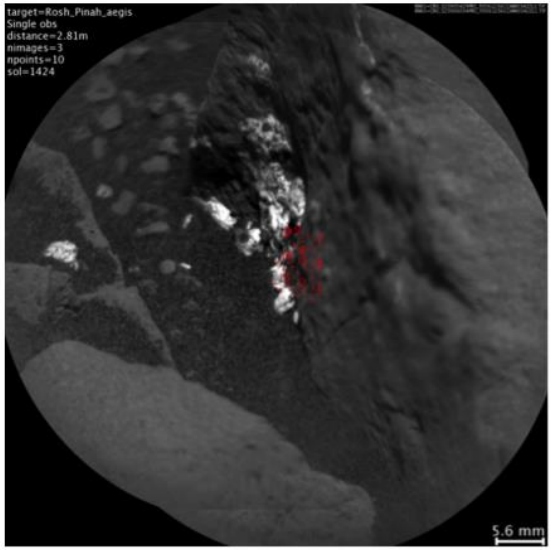
Results on Mars

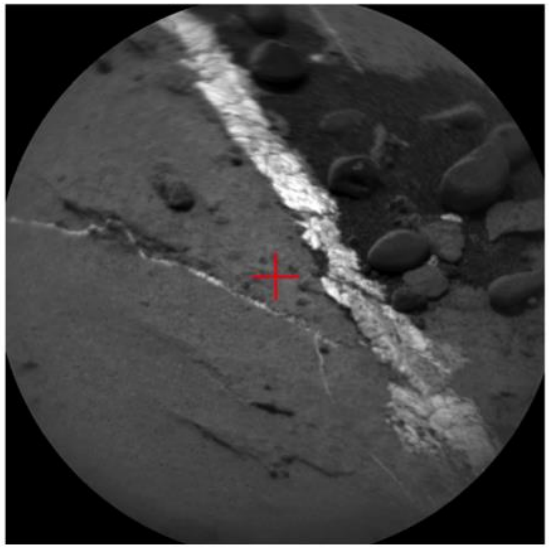
- AEGIS checkouts on MSL completed in early 2016
- System released for science team use May 2016
- First Use: sol 1343
- Target-finding parameters updated on sol 1400 with field experience
- NavCam (post-drive autonomous target selection) used 52 times, observing 57 ChemCam targets
    - After most drives
- RMI (autonomous pointing refinement) used 2 times
    - Only when important, small features are to be observed

Results: Pointing refinement

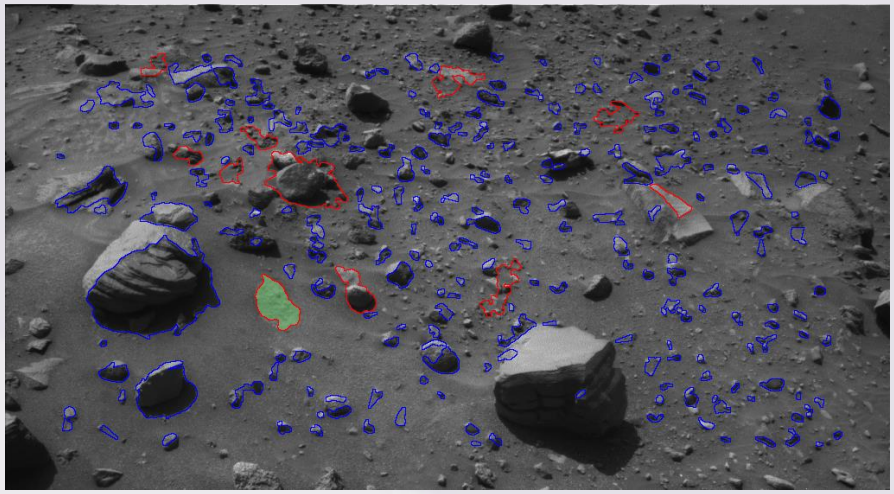
- Sol 1424 & Sol 1463
- Small, bright features
  - RMI FOV: 20 mrad Ø
- Initial (ground-selected) pointing missed target
- AEGIS corrected pointing and hit the target
- Saved observation – a manual retargeting second attempt would have been necessary. Not possible if rover were to drive in that plan



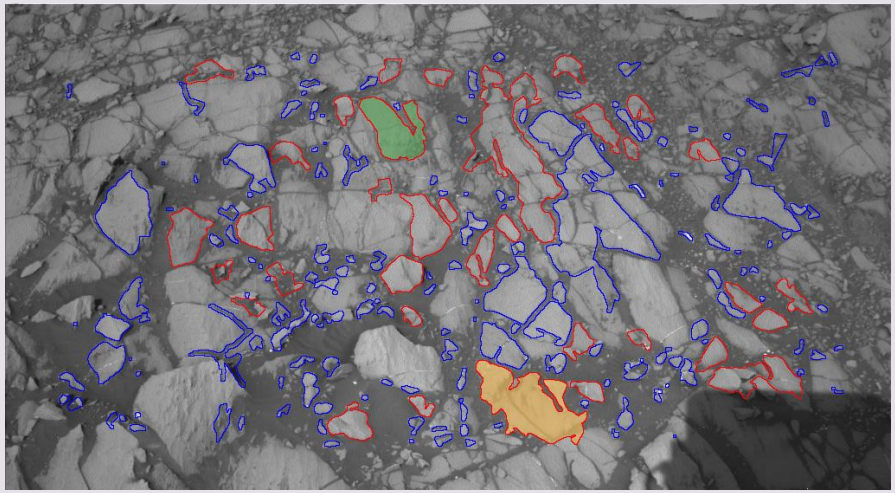




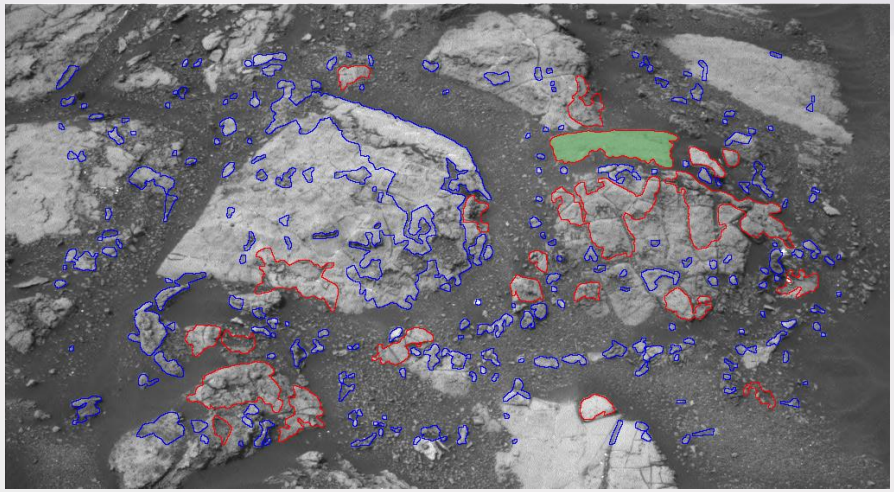
Results: Target selection



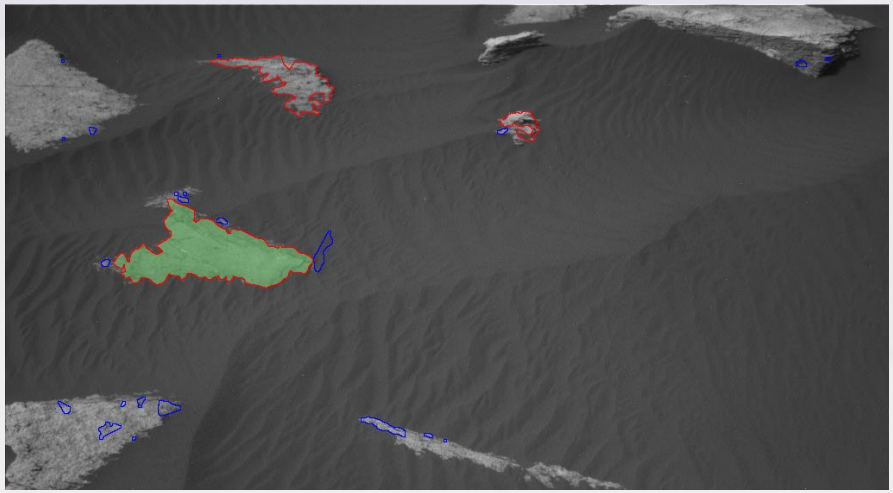
Sol 1400



Sol 1417



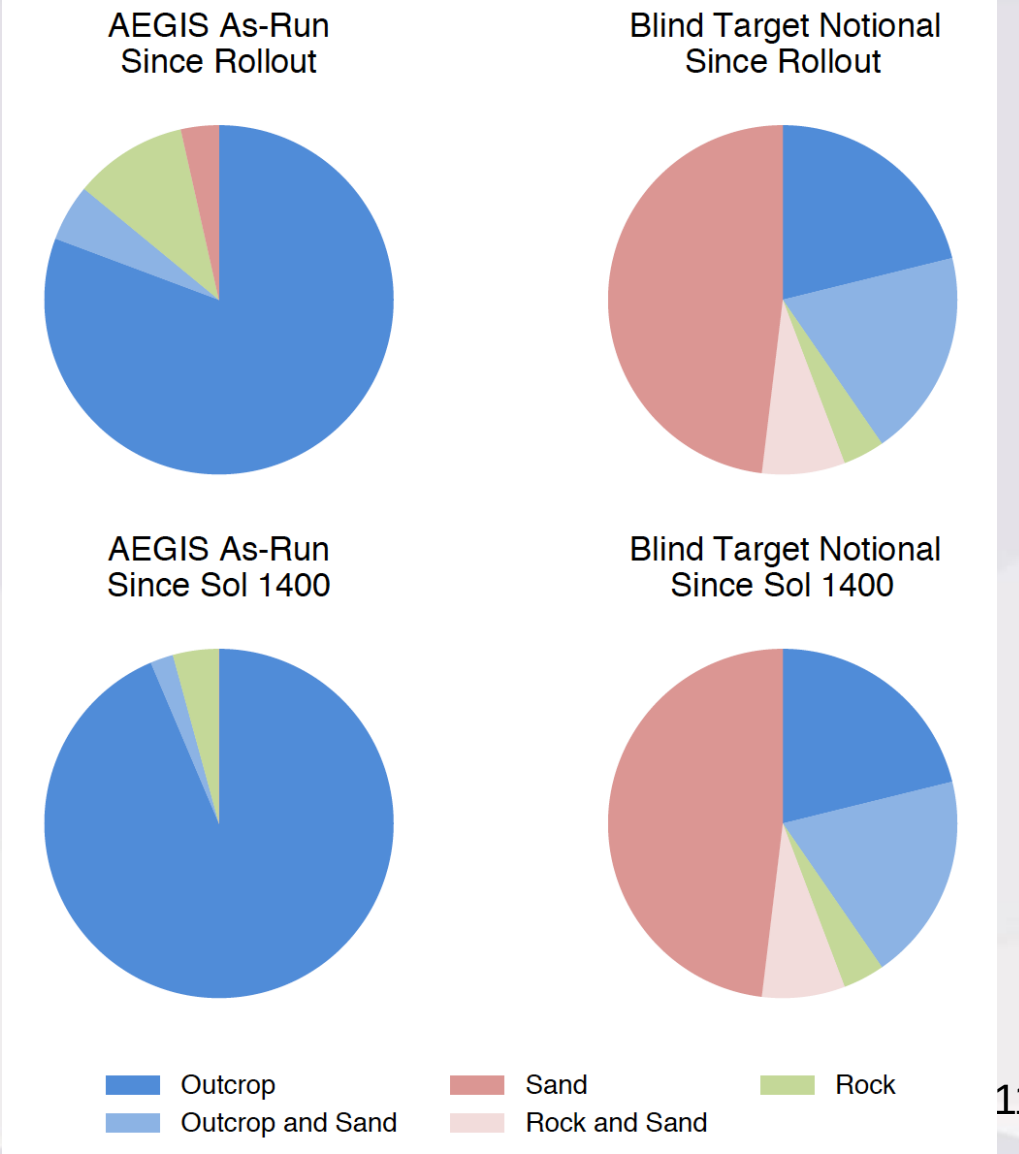
Sol 1481



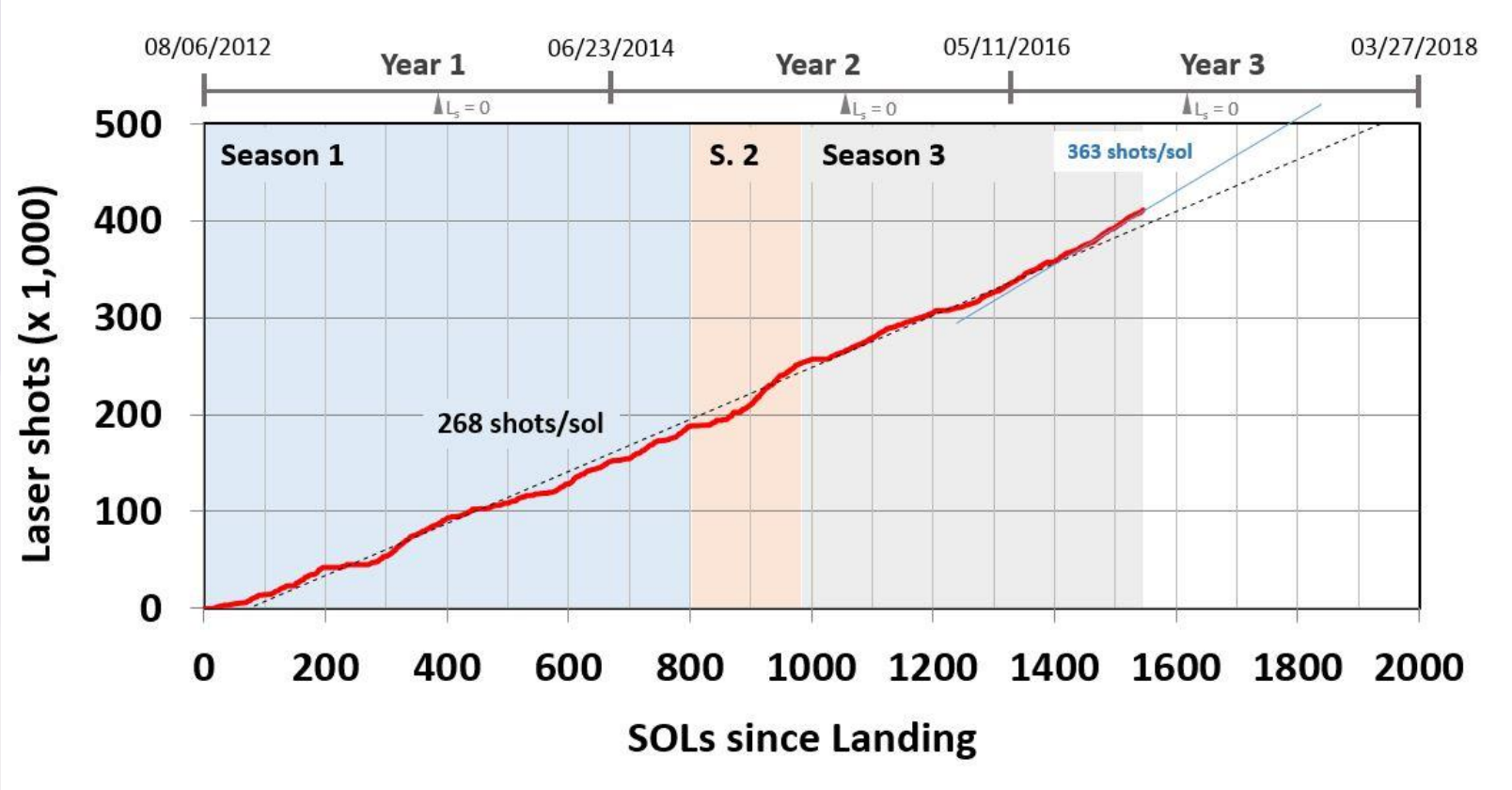
Sol 1636

Results: Target selection

- Set to find outcrop
- Since sol 1400, has hit exclusively outcrop in 93% of cases
- Remaining cases were float rock and outcrop with some sand cover
- Blind targeting modeled for same sols
  - Previous technique for aiming at fixed position relative to rover post-drive



More data from ChemCam



- Significant increase in rate of data return from ChemCam
- AEGIS rollout to science team on sol 1343